Small-scale Forestry (2008) 7:87–93
DOI 10.1007/s11842-008-9042-6

RESEARCH PAPER

Site Index Equation for Smallholder Plantations of *Gmelina arborea* in Leyte Province, the Philippines

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Accepted: 7 January 2008 / Published online: 23 January 2008

Abstract The equation SiteIndex = Height × Log(IndexYear+0.5)/Log(Age+0.5) is suggested as a robust way to classify site index of small private *Gmelina arborea* plantations in Leyte province in the Philippines. Estimates of site index from this equation correlate well with other indicators of site productivity, including the observed mean annual volume increment and soil depth. An alternative equation based on slope and soil depth offers an indication of potential site productivity on unforested sites where no crop trees are present.

Keywords Yemane · Gamar · Non-industrial private forest · Dendrometer · Parsimonious fit

Introduction

Gmelina (*Gmelina arborea* Linn., Roxb.) is planted extensively as a timber tree by smallholders in the Philippines. Few site equations have been published for this species, despite more than three decades of research (reported by Lauridsen and Kjaer 2002). Site index equations have been published for Bangladesh (Rahman and Ahmed 1995), Costa Rica (Rodríguez et al. 2004) and Nigeria (Greaves 1978; Onyekwelu 2003), but these equations are for industrial plantations and may not

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apply to smallholder situations where management is more variable. This paper describes the development of a site index equation for such smallholder plantings of *Gmelina arborea* in Leyte Province in the Philippines.

Gmelina arborea is a fast growing tree from the Verbenaceae family (Mabberley 1987), and has been planted widely throughout the tropics. The species occurs naturally from 5 to 30° N and 70 to 110° E in Asia, including India, Thailand and Vietnam, at sites between 50 and 1,300 m elevation (Dvorak 2003). Gmelina grows well on deep calcareous or loamy soils with 1,800–2,300 mm rainfall per annum (Lauridsen and Kjaer 2002).

In Leyte Province in the Philippines, gmelina is one of the top five tree species most widely grown by smallholder tree farmers (Cedamon et al. 2005). Most farmers in Leyte who have planted trees have relatively small plantings, often comprising only a few hundred trees per household (Emtage and Suh 2004). A survey of households showed that most trees are planted in conjunction with other crops, including coconuts and root crops (Cedamon et al. 2005), and silvicultural practices vary considerably (Baynes 2005). Many landholders in Leyte have established tree farms in areas unsuitable for agriculture, often with poor soil or steep slopes. As part of a project to assist smallholder tree growers improve productivity (described by Herbohn and Harrison 2005), an inventory of tree farms was completed and has provided basic data for the present study.

Research Method

Multistage sampling (Herbohn et al. 2005) provided 531 plots, including 247 plots in stands dominated by gmelina. Plots in which gmelina comprised fewer than half the stems, or in which there was evidence of harvesting, were excluded, leaving 216 plots for analysis. Plots were circular, and most (185) and most had a radius of 5 m, but in 31 plots the radius was increased to 10 m to ensure that at least seven trees/plot were sampled. The height of the tallest tree on the plot was measured with a laser dendrometer, and each stem was measured for diameter (dbh, using a girth tape), bark thickness (using a bark thickness guage), and upper stem diameters (with the laser dendrometer).

Inventory procedures identified homogenous stands, each of which was sampled with two or more plots. The heights of the tallest tree on each plot within a stand were averaged to obtain an estimate of the dominant height of 94 such stands containing two or more plots. One limitation of the data is that the estimate of stand age relied on a planting date provided by the owner, and could be established only to the nearest year. Another limitation is that none of the sample plots were remeasured, so that the temporal trend needed to be inferred by comparing plots, rather than by observing the growth trend on individual plots. Because of these limitations, only simple and robust height-age relationships were considered.

Linear regression analysis suggested that a simple relationship between height and age ($\mathrm{Ht} = \beta_0 + \beta_1 \mathrm{Log}(\mathrm{Age} + 0.5)$) provided an adequate and parsimonious fit to the data. A Box-Cox test indicated that no transformation of the dependent variable (Ht) was needed because the variance was homogeneous. The

transformation of the predictor variable (Log(Age + 0.5)) was a subjective choice to ensure reasonable predictions in young stands, but statistical analyses confirmed that this transformation provided a good fit to the data. Several environmental variables (e.g. aspect, slope, soil type and depth) were considered as possible covariates, but none offered a significant improvement to the fitted relationship.

Site Index Equation

The fitted height-age relationship has been estimated for stand-level data as:

$$\mathrm{Ht} = 6.971 \times \log_e(\mathrm{Age} + 0.5) \quad (\text{s.e. } 0.1365,\ \text{d.f. } 93,\ P < 0.0001). \tag{1}$$

The corresponding regression fitted to the individual plot data resulted in a similar parameter estimate (6.902, s.e. 0.1086, d.f. 215, $P < 0.0001$). In both cases, the estimate of the intercept (β_0) was not significantly different from zero ($P > 0.5$) and was omitted. Figure 1 illustrates that this equation provides a reasonable basis to classify site productivity. This equation may be rearranged to create a series of anamorphic site index curves (Fig. 1):

$$\mathrm{Ht} = \mathrm{SI} \times \mathrm{Log}(\mathrm{Age} + 0.5)/\mathrm{Log}(\mathrm{Yr} + 0.5) \tag{2}$$

or may be used to estimate site index directly as

$$\mathrm{SI} = \mathrm{Ht} \times \mathrm{Log}(\mathrm{Yr} + 0.5)/\mathrm{Log}(\mathrm{Age} + 0.5) \tag{3}$$

where SI is the site index and Yr is the reference age. Based on an analysis of 36 temporary plots, Onyekwelu (2003) suggested that 15 years appeared to be an optimal index age for gmelina in Nigeria. However, age 10 is commonly used as the index age for gmelina elsewhere (e.g. Rodríguez et al. 2004), and seems an

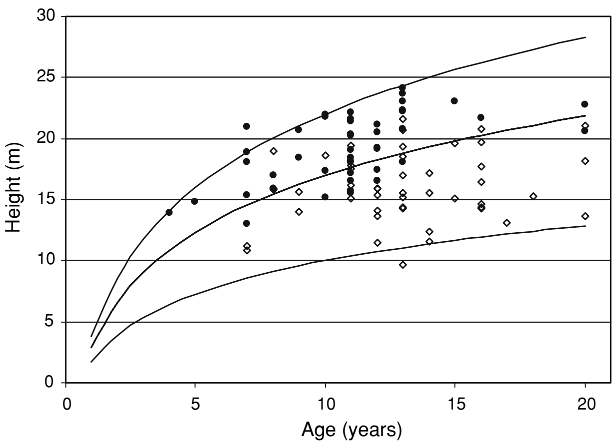

Fig. 1 Raw data and fitted model (Eq. 1). *Note*: Filled circles (●) represent stands with above-median volume MAI; white circles (○) represent stands with below-median volume MAI. The lines represent height-growth curves for sites indexed as 10, 17 and 22 m

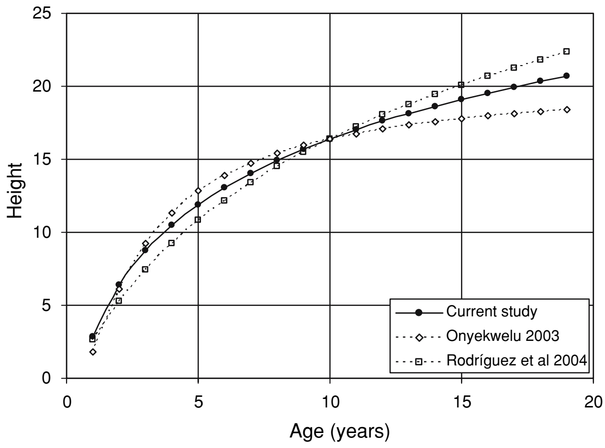

Fig. 2 Comparison of Eq. 1 with published site index equations for *Gmelina arborea* (Onyekwelu 2003; Rodríguez et al. 2004)

appropriate compromise for stands managed for short rotations in the tropics. Equation 1 provides height estimates similar to—and bounded by the estimates produced by—comparable equations elsewhere, including equations by Onyekwelu (2003) and Rodríguez et al. (2004), as illustrated in Fig. 2.

Discussion

One concern with data obtained through inventories such as in the present study is that the reported age may be subject to error, despite care by the inventory teams to check information with other informants and sources. Clearly, an error in the reported age will lead to an error in the calculated site index (Eq. 3). One way to check for such errors is to contrast site index estimates with estimates of mean annual increment (MAI). This is effective, because a 1 year in 10 errors in the stated age corresponds approximately to a 4% error in the SI estimate (because of the logarithmic transformation), but to a 10% error in MAI. Inventory procedures provided detailed stem measurements, enabling estimates of total stem volume—over bark, including branch wood, to 10 cm small-end diameter—or *derbholz* volume. This estimate of standing volume can be used to calculate volume MAI, which should be closely correlated with the site productivity (Skovsgaard and Vanclay 2008). Figure 1 illustrates the correlation between site index and MAI, lending support to the argument that the estimated site index does indeed reflect site productivity. Figure 3 further illustrates that this correlation also holds for the expected MAI-age relationship.

It is also instructive to compare site index and MAI directly. Figure 4 illustrates this relationship, without correcting for the MAI-age relationship. A strong relationship is evident, and some subtle site effects emerge; for instance, there is evidence of the effect of soil depth on estimated site index.

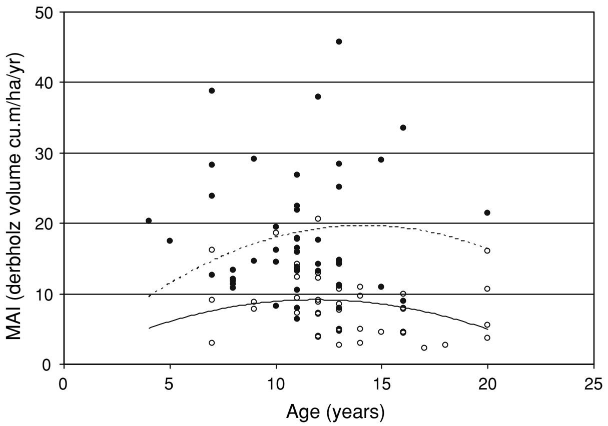

Fig. 3 Mean annual volume increment (MAI) trends for above- and below-median site-index stands. *Note*: Filled circles (●) represent stands with above-median site index; white circles (○) represent stands with below-median volume site index. The dotted and solid lines represent the quadratic relationship of best fit to the above- and below-mean stands respectively

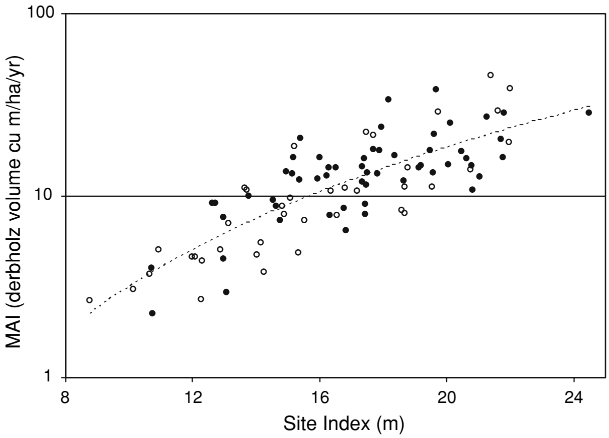

Fig. 4 The relationship between site index and volume MAI. *Note*: Filled circles (●) represent sites on soils deeper than 1 m, white circles (○) represent soils ≤1 m, and the dotted line is the trend indicated by a power curve

Equation 3 is only useful in situations where there are established trees, and is unsuited for the appraisal of bare land. The relationship between site index and the physical environment was investigated using environmental variables recorded in the inventory (Monterola et al. 2007), and led to the following relationship:

$$SI = 8.9 + 1.6 \times \text{SoilDepth} + 0.8 \times \text{Slope} \tag{4}$$

where SoilDepth (1: skeletal <0.05 m, shallow 0.05–0.15, medium 0.15–1 m, 4: deep >1 m) and Slope (1: level 0–3°, gentle 4–8°, moderate 9–16°, steep 17–26°, very steep 27–45°, 6: precipitous >45°) are categorical variables. While this

equation explains only 15% of the variation, all the parameter estimates are significant ($P < 0.0001$; s.e. 1.4, 0.35, 0.18 respectively). The equation may prove useful in 'greenfield' situations where no crop trees are present on the site.

There is no detectable effect of latitude or proximity to the coast on site index. Figure 5 illustrates the spatial distribution of the plots and of site index. It is evident that site index can vary considerably over short distances, reflecting micro-relief rather than more general geographic features.

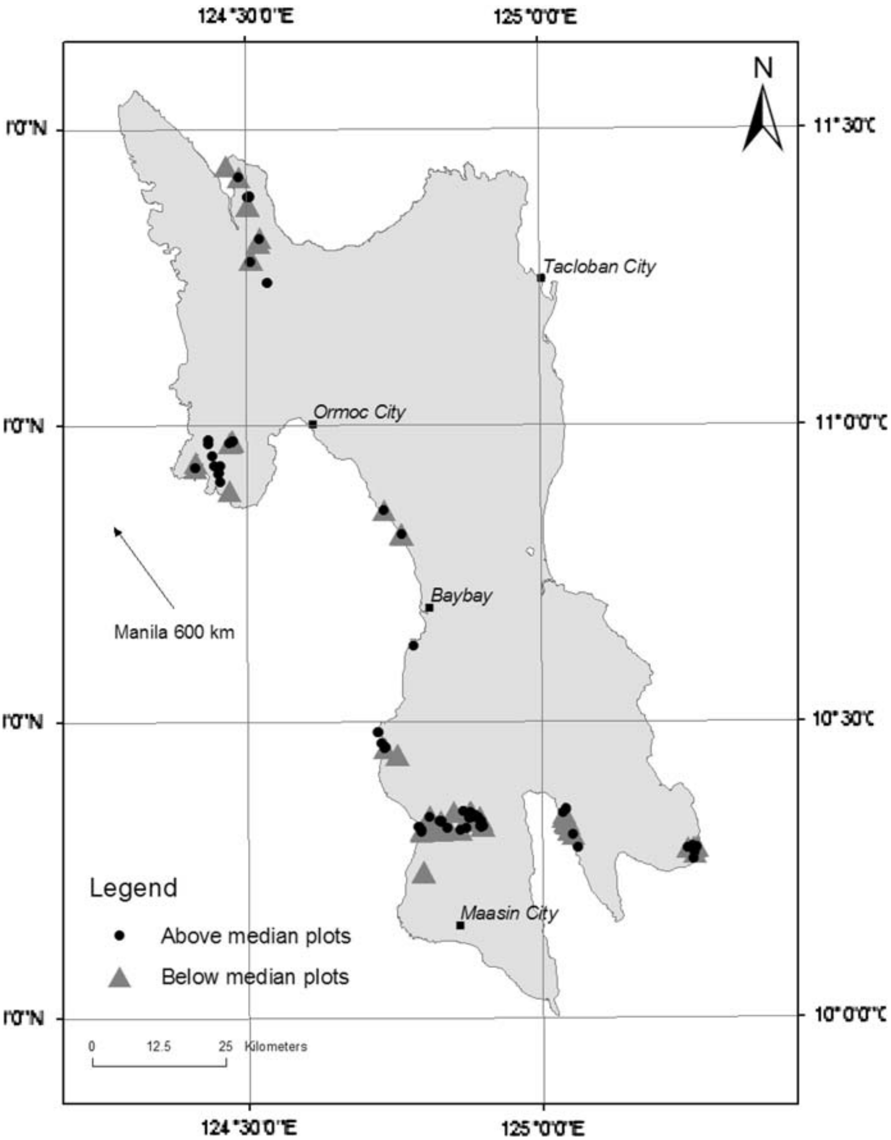

Fig. 5 Geographic distribution of plots and site index on the island of Leyte, the Philippines

Conclusion

The height-log(age) relationship provides a convenient basis for estimating site index of gmelina in smallholder plantations. Comparisons with other indicators of site productivity suggest that site index estimates derived from this relationship offer a reasonable indication of site productivity, applicable for growth modeling and yield prediction.

References

Baynes J (2005) The silviculture of small-scale forest plantations in Leyte, the Philippines: a preliminary survey. In: Suh J, Harrison SR, Herbohn JL, Mangaoang EO, Vanclay J (eds) ACIAR smallholder forestry project—improving financial returns to smallholder tree farmers in the Philippines, 15–17 Febuary, 2005, Ormoc City, the Philippines, pp 131–142

Cedamon E, Emtage N, Suh J, Herbohn J, Harrison S, Mangaoang E (2005) Present tree planting and management activities in four rural communities in Leyte Province. Ann Trop Res 27(1):19–34

Dvorak WS (2003) World view of *Gmelina arborea*: opporunities and challenges. In: Dvorak WS, Hodge GR, Woodbridge WC, Romero JL (eds) Recent advances with *Gmelina arborea*. CD-ROM. CAMCORE, North Carolina State University, Raleigh

Emtage N, Suh J (2004) Socio-economic factors affecting smallholder tree-planting and management intentions in Leyte Province, the Philippines. Small-Scale For Econ Manage Policy 3(2):257–270

Herbohn J, Harrison S (2005) Improving financial returns to smallholder tree farmers in the Philippines: issues and way forward. In: Herbohn J, Harrison S, Mangaoang E, Vanclay J (eds) Proceedings from the ACIAR project planning workshop, 15–17 February 2005, Ormoc City, Philippines, pp 7–19

Herbohn J, Harrison S, Vanclay J, Wardell-Johnson G (2005) Designing a strategy to sample tree farms on Leyte. In: Suh J, Harrison S, Herbohn J, Mangaoang E, Vanclay J (eds) Improving financial returns to smallholder tree farmers in the Philippines. ACIAR Smallholder Forestry Project ASEM/2003/052, Proceedings from the planning workshop, Ormoc City, Philippines, 15–17 February 2005, pp 203–210

Greaves A (1978) Site index curves for *Gmelina arborea* Roxb., Occasional Papers No. 2. Commonwealth Forestry Institute, Oxford

Lauridsen EB, Kjaer ED (2002) Provenance research in *Gmelina arborea* Linnz, Roxb.: a summary of results from three decades of research and a discussion of how to use them. Int For Rev 4(1):1–15

Mabberley DJ (1987) The plant book. Cambridge University Press

Monterola JGN, Morales F, Herbohn J, Vanclay J, Wardell-Johnson G, Mangaoang E, Harrison S (2007) Measurement of smallholder tree farms on Leyte Island. In: Harrison S, Bosch A, Herbohn J (eds) Improving the triple bottom line returns from small-scale forestry, Proceedings from an international conference, Ormoc, Philippines, pp 283–296

Onyekwelu JC (2003) Choosing appropriate index age for estimating site index of *Gmelina arborea* timber plantations in Oluwa forest reserve. Food Agric Environ 1:286–290

Rahman MM, Ahmed GU (1995) Estimating site index of gamar (*Gmelina arborea* Roxb.) from topographic variables in Chittagong hill tracts, Bangladesh. Ann For 3:5–14

Rodríguez FR, Aguilar DA, Roque RM, Montoya AM, Gamboa OM, Gamboa MA (2004) Manual para productores de Melina *Gmelina arborea* en Costa Rica. Cartago, Costa Rica

Skovsgaard JP, Vanclay JK (2008) Forest site productivity: a review of the evolution of dendrometric concepts for even-aged stands. Forestry. doi:10.1093/forestry/cpm041